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Short-term Multiagent Simulation-based Prediction in Mass Gatherings Decision Support

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Abstract
Mass gatherings emerging both for specific occasions and spontaneously, are naturally associated with the risk of stampedes and crowd clashes that may trigger dramatic consequences in shorter or longer term perspectives. In order to address such issues the present paper suggests the application of the agent-based modeling approach to short-term predictions of future states of large congregates of people. The latter is of prime value for practitioners who seek to identify the potentially dangerous areas where the risk of stampede-induced injuries is assumed the highest based on the estimations of the crowd pressure at a given spot. In this paper, we outline the algorithm for generating forecasts and on its basis, propose a system of decision support. The test of system applicability has been performed based on the 2018 World Football Championship stadium use case. The object under investigation is expected to be put into operation in 2018.

Keywords: mass gatherings, agent-based modelling, prediction modelling, decision support

1 Introduction

Despite the fact that large-scale human gatherings (both converging for civil and wartime occasions) have been emerging throughout history, only recently have they become a subject of a distinguishable multidisciplinary domain of research and practice. The reasons for that may be that mass gatherings have grown in frequency and scale (due to the development of transportation, infrastructure and communication technologies). Though initially being events at the local level, gatherings have transferred to the national and subsequently, the international level. Following an increase in the number of participants, the number of accidents has risen as well, increasing the overall risks associated with mass gatherings. According to some sources, during the last decades in the incidents, caused by the stampedes at mass gatherings, at least 7 thousand people lost their lives and around twice as many were injured [1]. Such estimations are at times imprecise, since there is a tendency to understate the casualties

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found in the literature that facilitates the demand for new methods of tracking mass gatherings that end in disasters.

Though the term "mass gathering" is commonly applied to events that draw together significant numbers of people, it requires formal clarification in the context of this paper. Today there are numerous alternating views on interpreting the expression. The key difference between the approaches to defining and assorting the mass events lies in the estimation of the number of participants [2] - in different instances, the lower limit can drift between hundreds and thousands of participants. For instance, in [3] authors propose a typology in which among the gatherings of the lower range that attract less than 1000 people, sport races and small musical concerts can be found, whereas the upper range events are represented by religious pilgrimages that can gather as many as 5 million people at the same time. Molloy et al [4] offer a more detailed classification: despite the potential number of people that certain types of events can attract, mass gatherings are defined based on the resources and time required for proper organization of the event. The lower range is set to 200 participants (mass gathering) and the upper range denotes events that exceed 1 million participants (mega mass gatherings).

The rest of the paper is structured as follows: Section 2 elaborates upon the existing literature dedicated to the investigation of mass gatherings pedestrian safety maintenance. Then, a general outline of the study is presented in Section 3, followed by the results of the experiments. Finally, the paper is culminated by the discussion of results, limitations of the described approach and directions for future studies.

2 Related Works

Researchers and practitioners from the public health domain highlight another perspective of mass gatherings – that regardless of whether they are managed or not, they essentially burden the capacities of the hosting community or local officials [5]. More specifically, these events can be characterized by conditions in which the delivery of medical services may be hindered [6]. Taking into account the fact that mass events are naturally different, such tasks as allocation of resources and estimation of risks strongly depend on the identification of a particular event in the range of the existing classifications of mass gatherings. For these reasons, classifications of mass gatherings are developed for the needs of practitioners in charge. For instance, the World Health Organization (WHO) proposes a classification [7] based on the repetitiveness (both temporal and spatial) and spontaneity of the events.

Some classifications are based on the purpose of gathering and the relevant characteristics that shall be taken into account when planning and maintaining security measures – composition of visitors, injuries and disorder risk factors etc. [7]. Other authors, for instance, Turris et al [8] divide mass gatherings into categories based on the spatial characteristics of the gathering venue – openness of space, number of spots that key events of the gathering occupy etc.

Despite the fact that mass gatherings perform important social, political, and cultural functions and facilitate the maintenance of participants' identity [9], they are still naturally associated with a number of risks participants and organizers might face. Today two basic categories of risks are highlighted in the literature: communicable and non-communicable ones. Recently there has been a substantial lag towards the studies concentrated on the first group of risks – namely, the prevention of the dissemination of the contagious disease, which is of increasing importance due to the rising numbers of visiting participants of mass events and associated risks of transferring contagious diseases across borders especially during the outbreaks. Steffen et al [10] among the non-communicable risk associated with mass gatherings highlight stampedes and clashes, air temperature impacts, emotional stress, injuries, exacerbation of existing disease in participants, malicious acts, and others.

In the present paper, we will address the issue of assisting security of those mass gatherings that lend themselves to prior organization and planning efforts (thus excluding the spontaneous throngs) and bring together congregations of numerical strength sufficient for creating conditions for injuries and casualties among the participants.

Nowadays the key issue associated with mass gatherings is the risk of injuries among the visitors in stampedes and pedestrian crashes. As prior research results suggest [1], the majority of casualties and injuries that occur during large events are associated with trauma, asphyxia and the related complications, along with heat-inflicted damage. The very mechanism of stampede emergence is, for the most part, understudied today, which hinders the development of the effective measures and technologies for casualty prevention. As it is assumed in [11], the majority of data on the causes of death of people in stampedes is not systematic: its sources are sporadic, since every stampede is a unique event that results from the interplay of different factors. However, there are attempts of systematizing the existing factors that contribute to the probability of stampede occurring [12], including misinformation, collapse of infrastructure, competitive behavior of visitors, environmental factors rand others.

As mentioned above, religious mass events are among the most problematic events from the pedestrian security point of view [12]. That is the main reason why those countries that host most frequent and large-scale pilgrimage events have major experience in both coping with pedestrian accidents and preventing them. Today India and Saudi Arabia might be distinguished as leading hosts of immense religious celebrations. So far the governments of both states have come up with a number of measures to address the issue of frequent pedestrian disasters caused by stampedes and other issues.

First, in order to assist the organizers and authorities in charge of maintaining the security of mass events, committees put forward recommendations on standard procedures aimed at minimizing the risk of accidents of various kinds. These are being prepared by governmental institutions and research agencies: for instance, the government of India [13] and researchers [14] issue reports on both the factors that shall be taken into account when organizing an event and best and worst practices that exist. In order to address analogous concerns, in 1975 Hajj Research Center emerged in Saudi Arabia, later reorganized and renamed "Custodian of the Two Holy Mosques Institute of Hajj Research", which aims to study and assist the events associated with pilgrimage.

Hajj pilgrimages have a rich history of stampede accidents [10]. Some of them have resulted in organizational changes in the very procedure of pilgrimage [15] as well as the modernization of the Jamarat bridge (considered to be the site of the most frequent stampede occurrence [16]) reconstruction attempts. The design of the bridge have been informed by the results of pedestrian agent-based simulation. Measures included the extension of the number and the capacity of emergency exit passages and footbridges. Moreover, the number of officers overlooking the safety of the pilgrims has increased. After the 2006 stampede in Mecca, the government of the hosting state decided to include interactive analytical systems – for instance, the one produced by CrowdVision [17] into the complex of pedestrian security measures. Despite the efforts, the goal of preventing stampedes during the Hajj is yet to be achieved, as in 2015 Mecca has once again experienced a stampede-related tragedy (in 2015 the tragedy unfolded in the area that is not covered by surveillance cameras [18]).

Almost the same situation is developing in India – where smaller and larger scale religious events are sometimes marked with casualties caused by the stampedes [12]. For instance, during the Kumbh Mela festival in 2013, held in Allahabad (one of the 4 traditional locations for the event that brings together millions of pilgrims), at least 30 people died in the stampede. In order to secure the visitors, a number of measures have been taken: an information support system (including a detailed map of the festival area) for visitors has been deployed, the territory of the festival has been divided into areas that have been provided with all the necessary elements of the infrastructure, all the roads and passages have been cleared of obstacles. Eventually, even with all those measures incorporated, casualties have marred the latest pilgrimages.

3 Prediction modelling

The records of the latest pedestrian disasters show that annual mass gatherings and other events of recurring nature, especially religious festivals that attract increasing numbers of devotees on a regular basis require new methods for both passive and active prevention of stampedes. A number of approaches to the development of management frameworks have been proposed in recent decades [13]. Advances in the sphere of analytic tools have led to the introduction of a field of decision-support systems designed monitoring the pedestrian flows and elaborating situation-aware strategies for the mitigation of the risks of mass casualties. Some of the proposed components of systems (for instance, RFID marks used for tracking pilgrims [19]) have been tested during actual mass gatherings, however, for the most part, the solutions found in the literature are prototypes, and despite rare examples, [20] mass gatherings are administered through crowd management strategies used for many decades which are only enforced by the concentration of larger amounts of resources. However, in order to reproduce and test the possible scenarios and identify potentially dangerous areas, prediction methods should be used.

The development of prediction methods is complex scientific research requiring deep analysis of cause-and-effect relationships between predictable processes, objects and elements, or the factors determining them. This is also connected to the significant variability of the processes in time and space. Thus, the method of predicting the behavior of a complex nonlinear system including crowd behavior is associated with modelling. Such modelling can be divided into two classes: (a) prediction of the behavior of the crowd at a specified time interval from the current moment and (b) scenario modelling, i.e. predictions based on some initial conditions (for example the class of “if-else” scenario).

In order to perform the study, an experimental method of short-term prediction of the dynamics of a crowd leaving a large stadium was developed. The method is adapted to the specific (currently under construction) "Zenit Arena" stadium, which is located on Krestovsky Island in St. Petersburg. The method uses Social Force [21] model implementation within the PULSE framework [22]. The total short-term forecasting algorithm is shown in Fig. 1.

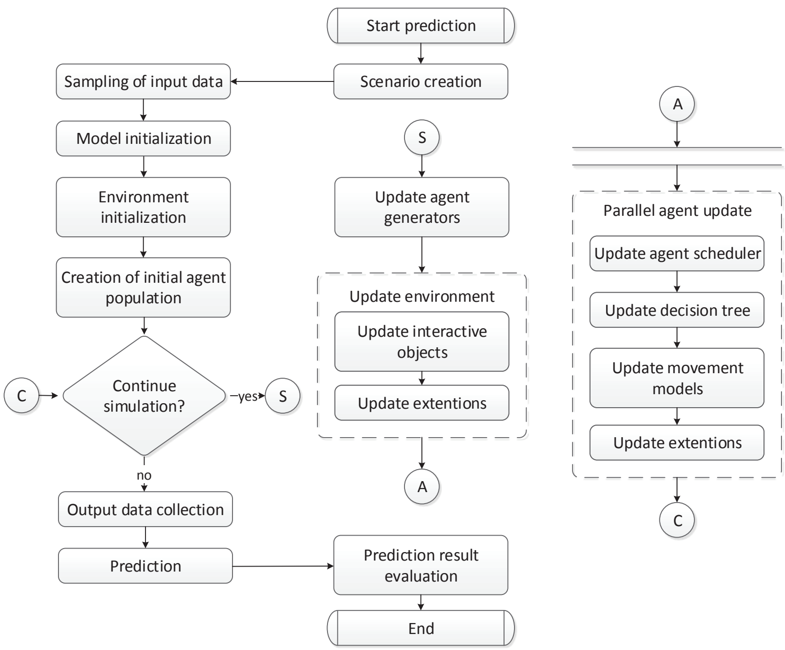


Figure 1: Algorithm of crowd simulation-based short-term prediction

For the purpose of the evaluation and analysis of prediction results density, speed and flow can be used (elements of fundamental diagram [23]) and relative "crowd pressure". For the purpose of evaluation and analysis of prediction results density, speed and flow can be used (elements of fundamental diagram [23]) and relative "crowd pressure". To assess the impact of surrounding agents normalized dimensionless value was introduced depending on: (a) current pressure; (b) limit pressure for the current settings defined in the simulation environment parameters (*repulsiveAgent*, *repulsiveAgentFactor*). The current pressure on the agent is according to the formula.

$$p = \sum_i |\bar{f_i}| \quad (1)$$

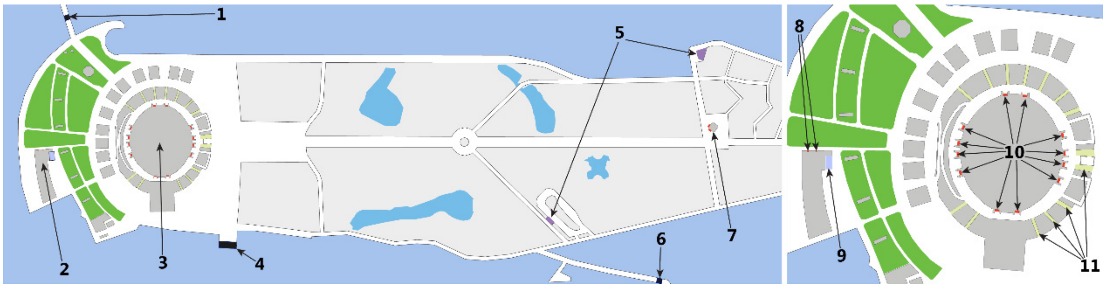
In this expression $\bar{f_i}$ is the total repulsive effect of other pedestrians. Pressure limit value was determined according to the following formula

$$p_{max} = \frac{repulsiveAgent * repulsiveAgentFactor * (10 * repulsiveAgent)^2 * 3}{40} \quad (2)$$

The normalized pressure is according to the expression

$$p' = \begin{cases} \frac{p}{p_{max}} & if \;\; p < p_{max} \\ 1 & otherwise \end{cases} \quad (3)$$

The scheme of simulated area was reconstructed with open data and current plans for the organization of the territory and infrastructure objects on it (Fig. 2).



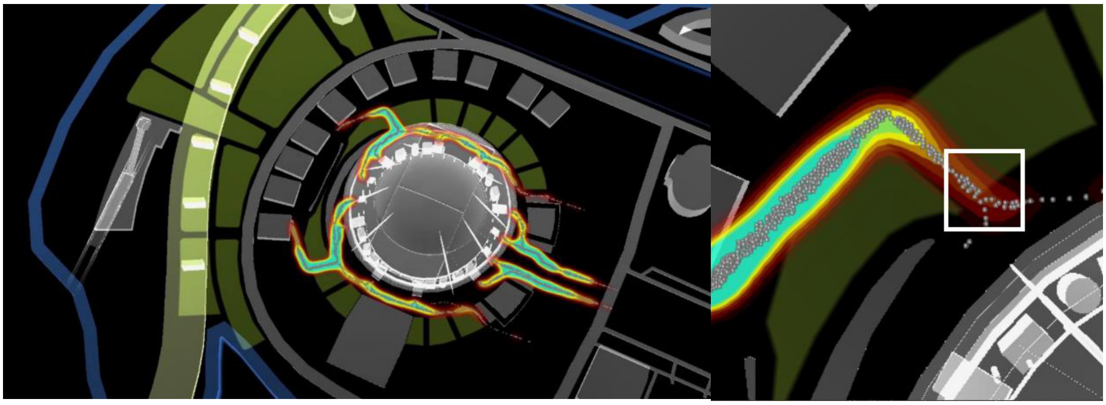
(a) (b)

Figure 2: Krestovsky Island model scheme (a) general view, (b) stadium area

Where 1 – pedestrian bridge (under construction), 2 – metro station Novokrestovskaya (under construction), 3 – stadium (under construction), 4 – aquabus stop (under construction), 5 – bus stop, 6 – bridge, 7 – metro station Krestovsky Island, 8 – metro station entrances, 9 – metro station exit, 10 – stadium gates, 11 – stairs.

4 Experimental Research

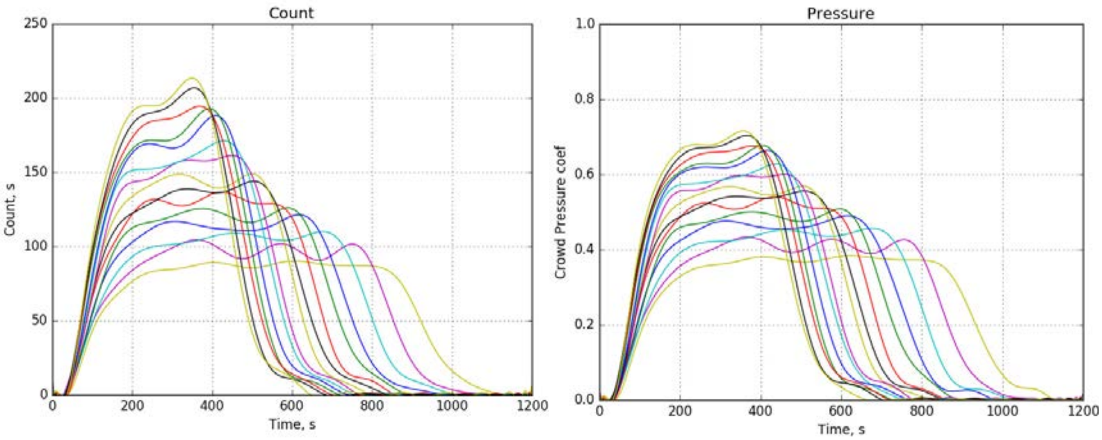
One of the traits of applying multiagent modeling to predict the states of pedestrian crowds is the uncertainty that affects the resulting forecasts. In order to assess the sensitivity of the method, a number of experiments have been carried out. The spatial setting for the experiment has been limited to the 20x20 square meters (Fig. 3b), where two crowd flows merge. The choice of the setting is motivated by the scenario to be reproduced in the experiment, namely, the variation in the flow characteristics of pedestrian flow at one of the entrances to the stadium. Each of the experiment runs has been performed for 20 minutes of model time. The results of the simulation are presented in the Fig. 4.



(a) (b)

Figure 3: (a) Mass gathering crowd dynamics forecast result visualization, (b) agent flow estimation zone – inside the square are the agents approaching the exit from the area surrounding the stadium

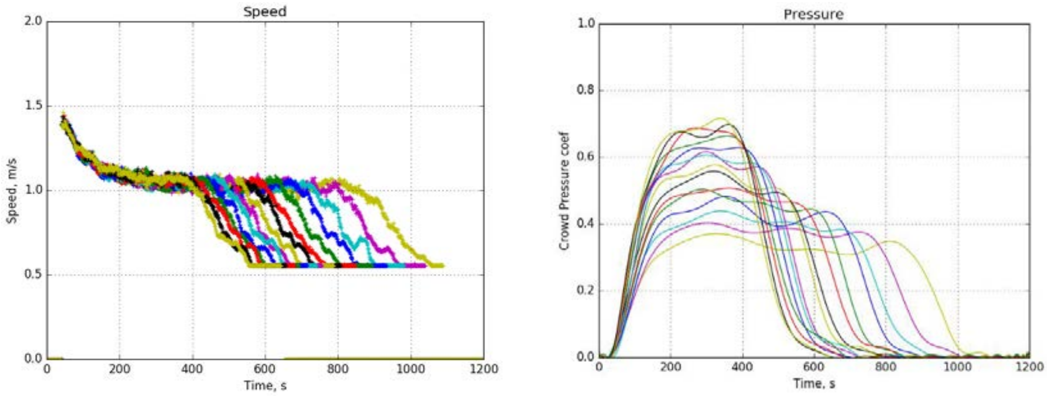
The metrics that have been used for quantifying the effect of the alteration of input values are the mean number of agents inside the square (Fig 4a), mean crowd pressure (Fig 4b) and the average speed (Fig 5a) of agents at the given part of the route (Fig. 3b) leading outside the stadium.



(a) (b)

Figure 4: Statistical ensemble of dependencies between the overall simulation time and (a) mean agent counts, (b) mean crowd pressure

The results of calculations show that the rate of crowd pressure depends on the number of people per given square. The average speed falls: remarkable situation when agents with the highest rate of time to elapse before a crowd of Education, while the agents with the lowest rate of still leave the territory in the process of reduction of the crowd (Fig. 5a).



(a) (b)

Figure 5: Statistical ensemble of dependencies between the overall simulation time and (a) the mean speed inside the given area, (b) mean crowd pressure during the sudden increase of speed (i.e. due to rain)

In addition, we consider the problem of the influence of some random factors on the prediction result: the individuals in the crowd trying to speed up the movement due to external causes, such as the occurrence of rain (Fig. 5b). This is modeled and simulated as an external event, which (on the 300th second) leads to a slight increase of speed. From Fig. 5b it is clear that on the test site when the speed increases due to the rain (300th second), crowd pressure is also increased. However, during a 20-50 returns to the original value.

5 Discussion & Conclusion

In conclusion, in order to choose the optimal strategy for crowd management at different stages of mass gathering organization, decision makers might be assisted not only with the help of the real-time monitoring systems which are indispensable, but with short-term predictions of future states of the crowd produced through agent-based models. The latter can supply data on density, unidirectional speed of pedestrians, and flow metrics (e.g. fundamental diagram) of the crowd in the runtime. Moreover, the realization of the Social Force used in this research allows one to acquire the crowd pressure variable values interactively by updating the force components.

However, we assume herein that the use of crowd density as a predictor of stampedes shall be revised. On the one hand, crowd density is undoubtedly linked to the risk of injuries especially in physically limited spaces, and in terms of planning, it suggests the basis for comparison of different crowd management strategies. On the other hand, there are other factors, including the confounding ones, that risk being overlooked – for instance, the effects of air temperature, weather conditions, information available to participants, substance use during mass gatherings etc.

Apart from the purely practical use case described herein, we are looking forward to applying the system to answering more fundamental research questions (which is, in return, expected to improve the reliability of pragmatic forecasts). For instance, the issue of pedestrians applying different (sometimes conflicting) navigation and obstacle avoidance strategies to different contexts might have substantial impact on the precision and reliability of predictions. Moreover, identification of conditions that might facilitate stampedes rather than just situations where the density of the crowd is increased can be beneficial. Today there is no consensus in the literature on the works of stampede mechanics: thus different assumptions, related to balance, environmental factors and physical characteristics of venues may be tested in the virtual space in order to later enrich decision support and elaborate upon recommendations for organizers of mass gatherings.

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References

[1] R. Steffen, A. Bouchama, A. Johansson, J. Dvorak, N. Isla, C. Smallwood, and Z. A. Memish, “Non-communicable health risks during mass gatherings,” *Lancet Infect. Dis.*, vol. 12, no. 2, pp. 142–149, 2012.

[2] K. M. Ngai, W. Y. Lee, A. Madan, S. Sanyal, N. Roy, F. M. Burkle Jr, and E. B. Hsu, “Comparing two epidemiologic surveillance methods to assess underestimation of human stampedes in India,” *PLoS Curr.*, vol. 5, 2013.

[3] S. A. Turris, A. Lund, A. Hutton, R. Bowles, E. Ellerson, M. Steenkamp, J. Ranse, and P. Arbon, “Mass-gathering health research foundational theory: Part 2-event modeling for mass gatherings,” *Prehosp. Disaster Med.*, vol. 29, no. 6, pp. 655–663, 2014.

[4] M. Molloy, A. Sherif, S. Natin, and J. McDonnell, “Management of Mass Gatherings,” *Koenig Schultz’s Disaster Med. Compr. Princ. Pract.*, pp. 228–253, 2009.

[5] W. H. Organization and others, “Communicable disease alert and response for mass gatherings: key considerations,” *Geneva WHO*, pp. 32–33, 2008.

[6] P. Arbon, “Mass-gathering medicine: a review of the evidence and future directions for research,” *Prehosp. Disaster Med.*, vol. 22, no. 02, pp. 131–135, 2007.

[7] W. H. Organization and others, “Public Health for Mass Gatherings: Key Considerations,” 2015.

[8] S. A. Turris, A. Lund, and R. R. Bowles, “An analysis of mass casualty incidents in the setting of mass gatherings and special events,” *Disaster Med. Public Health Prep.*, vol. 8, no. 02, pp. 143–149, 2014.

[9] C. N. Buzinde, J. M. Kalavar, N. Kohli, and D. Manuel-Navarrete, “Emic understandings of Kumbh Mela pilgrimage experiences,” *Ann. Tour. Res.*, vol. 49, pp. 1–18, 2014.

[10] Z. A. Memish, G. M. Stephens, R. Steffen, and Q. A. Ahmed, “Emergence of medicine for mass gatherings: lessons from the Hajj,” *Lancet Infect. Dis.*, vol. 12, no. 1, pp. 56–65, 2012.

[11] National Disaster Management Authority, “Managing Crowd - National Disaster Management Authority,” *Managing Crowd - National Disaster Management Authority*, 2014. .

[12] F. T. Illiyas, S. K. Mani, A. P. Pradeepkumar, and K. Mohan, “Human stampedes during religious festivals: A comparative review of mass gathering emergencies in India,” *Int. J. Disaster Risk Reduct.*, vol. 5, pp. 10–18, 2013.

[13] M. Yamin, “A Framework For Improved Hajj Management And Future Research,” *ENTIC Bull*, vol. 2, no. 08, 2008.

[14] A. Prasun and P. Dixit, “Stampede Management For Religious Events In India.”

[15] M. Mohandes, M. A. Haleem, A. Abul-Hussain, and K. Balakrishnan, “Pilgrims Tracking Using Wireless Sensor Network,” in *Advanced Information Networking and Applications (WAINA), 2011 IEEE Workshops of International Conference on*, 2011, pp. 325–328.

[16] Q. A. Ahmed, Y. M. Arabi, and Z. A. Memish, “Health risks at the Hajj,” *Lancet*, vol. 367, no. 9515, pp. 1008–1015, 2006.

[17] J. Wakefield, “Can Technology Help Avoid Stampedes?,” *Can Technology Help Avoid Stampedes?*, 2013.

[18] S. P. and D. W. Sarah Almukhtar, Larry Buchanan, Josh Keller, Alicia Parlapiano, “How the

Hajj Stampede Unfolded,” 2015.
[19] K. S. Ravi, M. A. Aziz, and B. V. Ramana, “Pilgrims Tracking and Identification Using RFID Technology,” *Adv. Electr. Eng. Syst.*, vol. 1, no. 2, pp. 96–105, 2012.
[20] A. Johansson and D. Helbing, “Pedestrian flow optimization with a genetic algorithm based on boolean grids,” in *Pedestrian and evacuation dynamics 2005*, Springer, 2007, pp. 267–272.
[21] D. Helbing and P. Molnar, “Social force model for pedestrian dynamics,” *Phys. Rev. E*, vol. 51, no. 5, p. 4282, 1995.
[22] V. Karbovskii, D. Voloshin, A. Karsakov, A. Bezgodov, and A. Zagarskikh, “Multiscale Agent-based Simulation in Large City Areas: Emergency Evacuation use Case,” *Procedia Comput. Sci.*, vol. 51, pp. 2367–2376, 2015.
[23] N. Geroliminis and C. F. Daganzo, “Existence of urban-scale macroscopic fundamental diagrams: Some experimental findings,” *Transp. Res. Part B Methodol.*, vol. 42, no. 9, pp. 759–770, 2008.